United Technologies Research Center

Novel Refrigerant Leak Detection Technology Development

In the mid-1990s, 75 percent of the refrigerants produced were used to replace refrigerants that had leaked out of refrigeration systems. Furthermore, the refrigerant leakage posed a significant environmental concern because refrigerants are destructive to the atmosphere's ozone layer. Therefore, most of the world community had agreed to use leak-detection techniques during the production of components containing refrigerant in order to reduce leakage. Refrigerants containing both chlorine and fluorine atoms are the most harmful to the ozone layer. At the time of the project research, manufacturers were able to detect only large leakage rates by using a mechanical "sniffer" device that detected chlorine- and fluorine-based refrigerants. However, sniffers could not detect minute leakage rates; this level of detection would require more advanced technology.

As part of the 1995 focused program, "Advanced Vapor Compression Refrigeration Systems," United Technologies Research Center, DeMaria Electro-optics Systems, and Adaptive Optics Associates applied for and received an Advanced Technology Program (ATP) award to research and develop more sensitive leak-detection technology. By the end of the ATP project, additional funding was needed to develop the technology. Although United invested its own resources for further development, refrigerant component manufacturing customers did not buy the device, due in part to the high cost of replacing their existing expensive equipment. As of 2004, the original partner companies are still in business, but are not pursuing further development of their leak-detection technology.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
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Research and data for Status Report 95-06-0011 were collected during July 2004.

Refrigerant Leakage Costs the Manufacturing Industry Millions

A refrigerant is a fluid used in cooling components of various machines to maintain a required temperature by removing unwanted heat. Seventy-five percent of the refrigerants that were produced in the mid-1990s were used to replace leaked refrigerant from systems such as refrigerators and automobile air conditioners. The leakage problem was due, in part, to the difficulty in detecting small refrigerant leaks in components during manufacturing and because existing leak-detection techniques relied on imprecise methods. However, it was estimated that if leaks in the defective components could be detected with greater sensitivity during the manufacturing process, component owners would save $650 million per year in refrigerant costs. Also, the industry could significantly reduce the accidental emission of ozone-depleting chemicals and their accompanying adverse environmental effects.

Refrigerant Leak-Detection Technologies Were Inadequate

In 1995, the techniques in use for leak detection in a factory's assembly line were either not sensitive enough or were not economical. The simplest, least expensive, and least sensitive technique was to apply a soap film to a welded component and watch to see if bubbles developed, which indicated that there was a leak.

This method could only detect the grossest of leaks. Pressurizing a welded unit and immersing it into a tank of water to look for bubbles would also indicate a leak, but with a level of accuracy that was similar to the soap-film technique.

A more sensitive technique was vacuum decay detection. This involved removing all the air to create a vacuum inside the welded component that needed testing. The component was then connected to an instrument that would measure the internal pressure to see if the pressure increased due to air leaking into the component. Although this method was more sensitive than the soap-film method, it could not pinpoint the source of the leak in the component.

Detectors based on ionization processes, or "sniffers," were more sensitive still. A sniffer device has a nozzle that sucks any leaking gas into an ionizing chamber where the gas reacts with a substance that causes electrons to be released from the substance. The released electrons are measured in the ionizing chamber as electrical current. Although this method is more sensitive than the ones described previously, large components with 60 welded parts took as long as 18 minutes to be tested, an unacceptable and uneconomical amount of time in an assembly-line setting. (These four leak-detection techniques are representative of the methods used in 1995.)

Partnership Forms to Advance Leak-Detection Technology

Prior to the start of the project, three companies formed a joint venture to develop a more sensitive and economical leak detector that could be used during refrigeration component manufacturing. The partners were the industrial research laboratory at United Technologies Research Center (UTRC), the research arm of United Technologies Corporation; DeMaria Electro-optics Systems, a world leader in laser technology; and Adaptive Optics Associates (AOA), an electro-optics laboratory. The unique detector design proposed by the partnership would be technically risky because it would incorporate a CO_2 laser into a handheld unit (see Figure 1).

Figure 1. Shown above is the prototype handheld laser leak detector. The armored fiber optic cable exits from the rear of the laser barrel to the left of the operator's hand. The small metal tube mounted on top of the barrel houses the visible laser guide beam to assist the operator in aiming the detector.

The joint venture's goal was to develop a detector that would enable the industry to economically detect leak rates of less than 3 grams per year.

The companies' research also targeted the need to preserve the atmosphere's ozone layer.

The risk involved several critical aspects of the detector that needed considerable development and testing, such as the CO_2 laser pulse, the fiber optic cable that would carry the detected data to the processor outside the handheld unit, and an algorithm for the data processor. Because the proposed technology was more advanced and more expensive to develop than any leak-detection technology in use at the time, the partners submitted a proposal to ATP to support their endeavor. They received ATP funding for a two-year project starting in late 1995 under the focused program, "Advanced Vapor Compression Refrigeration Systems." UTRC, the project lead, had already invested about $1 million between 1991 and 1995 to explore technologies in advanced leak detection.

Besides reducing the cost of manufacturing refrigerant that is lost due to leakage, the companies' research also targeted the need to preserve the atmosphere's ozone layer. Chlorine and fluorine, both contained in chloroflurocarbon (CFC) refrigerants, are extremely hazardous to the ozone layer.

Laser Technology Used for Refrigerant Leak Detection

The joint venture partners wanted to improve the sensitivity of leak detection in the factory setting from 100 grams per year to 3 grams per year. Reducing the leakage rate from 100 to 3 grams represented a 33-fold improvement, a goal that required a significant advancement in technology. The handheld device that the partnership proposed to develop was a combination of technologies: a gaseous laser beam to detect leaks, fiber optics to transmit the data collected by the device, and a digital signal processor (DSP) to analyze the sound produced if a leak was detected. The user would hold the device 1 to 3 feet away from the welded sites and would point it at the refrigeration component. The user would then activate the laser. If a gas leak were present, the leaking gas would interact with the laser CO_2 photons and would create a gas pressure (acoustic) wave. The acoustic wave would be detected as a sound by a microphone in the handheld unit. The fiber optic cable would then transmit these data to the DSP, where the sound data were analyzed to determine the location and size of the leak. The DSP could analyze leaks as small as 3 grams per year or higher.

Leak Detector Presents Design Challenges

The team identified three critical parts of the leak detector that would need development: the CO_2 laser pulse, the fiber optic cable for the transmission medium of the detector, and the DSP algorithm that would be used to analyze the signal collected. The partners intended to focus on developing the following components of the handheld detector:

- **CO_2 Laser Pulse.** The team would refine the design of the CO_2 laser pulse emitted by the handheld device. A CO_2 laser is made of light photons emitted from excited CO_2 gas molecules. CO_2 lasers, though inexpensive, are inherently inefficient at this task, so major design modifications would be necessary. For example, the correct wavelength of the CO_2 photons in the pulse needed to be determined.
- **Fiber Optic Cable.** The team would enhance an infrared fiber optic cable that minimized loss of the transmitted signal. The fiber optic cable transmitted the data gathered from the microphone that picked up the sound from a leak. All fiber optic cables experience some loss of signal during operation. The more signal lost, the less accurate the measurement of the collected data would be. The factory setting, in particular, was a more rugged environment than the medical environment for which the fiber was originally designed. The team would need to find a way to prevent background factory noise from "drowning out" the acoustic wave collected from the tested weld.
- **DSP Algorithm.** The team would develop a DSP algorithm to accurately analyze the acoustic waves. The algorithm would be installed as part of the software on the DSP chip. Such an algorithm would need to distinguish between the sounds made by a leak interacting with the laser and the factory background noise. In analyzing a sound wave made by the interaction of a leaking gas with the laser, the DSP algorithm must be sensitive enough to correlate the loudness or softness of the sound with a leak rate.

Partners Cooperated to Build a Prototype Handheld Leak Detector

In the early 1990s, a competitor built a detector using a CO_2 laser, but it was not a handheld unit. The device could not overcome noise levels in the factory environment, so the data gathered by the device were compromised. The UTRC partnership hoped to overcome the interfering noise problem.

UTRC and DeMaria Electro-optics Systems planned to evaluate several technologies for the infrared gas pulse generator aspect of the handheld design. DeMaria would help develop the optimum infrared pulse shape and duration to achieve the highest sensitivity in leak detection. Moreover, the technology would be developed with an eye toward transferability in detecting new, as-yet-undeveloped refrigerants. There are several types of refrigerants in the CFC family of refrigerants. If the team could find a CO_2 laser frequency that would react with most of them, even ones that had not yet been developed, this would provide an additional economic benefit to the ATP-funded project research.

AOA would evaluate several types of optic fibers available for use in the prototype, with the assistance of Rutgers University. AOA brought extensive expertise to the project, including 15 years of experience in pressure wave (acoustic) sensors; micro-optics; high-speed, high-resolution cameras; and high input/output bandwidth commercial processors. In an assembly-line setting, the proposed leak detector would need all of these capabilities.

Joint Venture Completes Prototype Device

After the ATP-funded project concluded, UTRC received additional money from other government agencies, internal funding, and other private sources to develop the technology. However, by 2003 they had ceased development. By the project's end, the team had developed a working prototype that could detect leaks of several refrigerant gases at a leak level of approximately 2.8 grams per year at a distance of 1 to 3 feet from a known, calibrated leak. However, despite a five-month project extension, the laser pulse emitter still needed more development to reduce its cost. Consequently, the lack of an economical prototype forestalled efforts to develop a marketable product. Even though the potential customers for the device were currently relying on technology that was often unreliable, they had already invested millions of dollars in their existing technologies and were unwilling to spend more. Carrier, a subsidiary of United Technologies Corporation, purchased a prototype handheld unit from UTRC, but suspended further testing and development due to a reduction in research funds. Then Carrier decided to shut down its research division in 2001, further reducing the possibility of reviving the technology.

DeMaria also exhausted funding from non-ATP governmental and private sources in the years immediately following project conclusion. DeMaria was subsequently acquired in 2001 by Coherent, a laser manufacturer for the research community. AOA decided not to pursue further development of the technology following the conclusion of the project. In post-project surveys conducted by ATP in 2001 and 2003, all three partners cited cost of development, lack of funding, competition, and uncertain market demand as contributing factors to discontinuing research into this technology. The markets for the laser emitter for the handheld unit were also limited.

As of 2004, refrigeration component manufacturing companies primarily use the sniffer technology. According to Bill Veronesi of UTRC, a principal investigator on the project, not much progress has been made in improving sniffer technology sensitivity in the years after this project ended. Although no product resulted from this project, the company was granted five patents. UTRC also completed one presentation to the Connecticut Microelectronics and Opto-electronics Consortium related to aspects of photo-acoustic leak-detection technology using lasers.

Conclusion

Since the 1970s, engineers have sought ways to detect refrigerant leaks with greater accuracy to meet the world community's standards on atmospheric ozone preservation and to save money during the refrigeration component manufacturing process by producing fewer defective components. Three companies, United Technologies Research Center (UTRC), DeMaria Electro-optics Systems, and Adaptive Optics Associates, formed a joint venture to develop the first handheld leak detector that incorporated a laser, a sound detector, and a digital signal processor.

Each partner worked on a specific part of the detector development. Rutgers University was also involved in evaluating the optimum fiber optic cable to use to transmit the collected signal from the units tested. However, at the project's end, the laser in the prototype detector was still too expensive to use in a marketable product. Although UTRC and DeMaria spent additional non-ATP funds in the post-project years, they were not able to produce an economical product. UTRC did receive five patents related to the ATP-funded project, and researchers made one presentation on the subject of laser photo-acoustic detection techniques.

PROJECT HIGHLIGHTS
United Technologies Research Center

Project Title: Novel Refrigerant Leak Detection Technology Development

Project: To develop a novel leak-detection technology that is 33 times more sensitive than existing methods for detecting leaks in air-conditioning systems during manufacturing.

Duration: 10/1/1995–11/15/1997 (project was extended 6 months)
ATP Number: 95-06-0011

Funding (in thousands):**

ATP Final Cost	$ 708	49%
Participant Final Cost	743	51%
Total	$1,451	

Accomplishments: With ATP funding, United Technologies Research Center and its two partner companies, DeMaria Elector-optics Systems and Adaptive Optics Associates, successfully demonstrated a prototype device that met the target leak detection level of 3 grams per year for chloroflurocarbons.

The following patents for technologies related to the ATP-funded project: were granted:

- "Photo-acoustic leak detector with improved signal-to-noise response"
  (No. 5,780,724: filed March 27, 1997; granted July 14, 1998)
- "Photo-acoustic leak detector with baseline measuring"
  (No. 5,824,884: filed April 16, 1998; granted October 20, 1998)
- "System to control the power of a beam"
  (No. 6,089,076: filed September 18, 1998; granted July 18, 2000)
- "Method and apparatus to diffract multiple beams"
  (No. 6,154,307: filed September 18, 1998; granted November 28, 2000)
- "Photo-acoustic leak detection system"
  (No. 6,327,896: filed March 20, 2000; granted December 11, 2001)

Commercialization Status: No leak detection product was commercialized.

Outlook: The outlook for this technology is weak due to the expense of further development and the lack of customer interest.

Composite Performance Score: *

Focused Program: Advanced Vapor Compression Refrigeration Systems, 1995

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Subcontractors:

- Coherent, Inc. (formerly DeMaria Electro-optics Systems, Inc.)
  Santa Clara, CA
- Adaptive Optics Associates, Inc.
  Cambridge, MA

Presentations: UTRC gave the following presentation on the ATP-related project:

- "Photo-acoustic System for the Detection of Leaking Refrigerants." Connecticut Microelectronics and Opto-electronics Consortium (CMOC '98), Trinity College, Hartford,CT, March 24, 1998.

** As of December 9, 1997, large single applicant firms are required to pay 60% of all ATP project costs. Prior to this date, single applicant firms, regardless of size, were required to pay indirect costs.

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